Ultrasonic NDE of Multilayered Structures

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This project developed ultrasonic NDE based on guided and bulk waves in multilayered structures using arrays. First, a guided wave technique was developed by preferentially exciting dominant modes with energy in the layer of interest via an ultrasonic array. Second, we used Fermat's principle of least time, as well as wave-based properties, with a bulk wave technique, to reconstruct array data and image the multilayered structure.

Inspecting multilayered structures with a guided wave relies on exciting modes with sufficient energy in the layer of interest. Multilayered structures are modeled to determine the possible modes and their distribution of energy across the thickness.

Bulk wave imaging algorithms were developed to overcome the difficulties of multiple reflections and refractions at interfaces. Reconstruction algorithms were developed to detect and localize flaws.

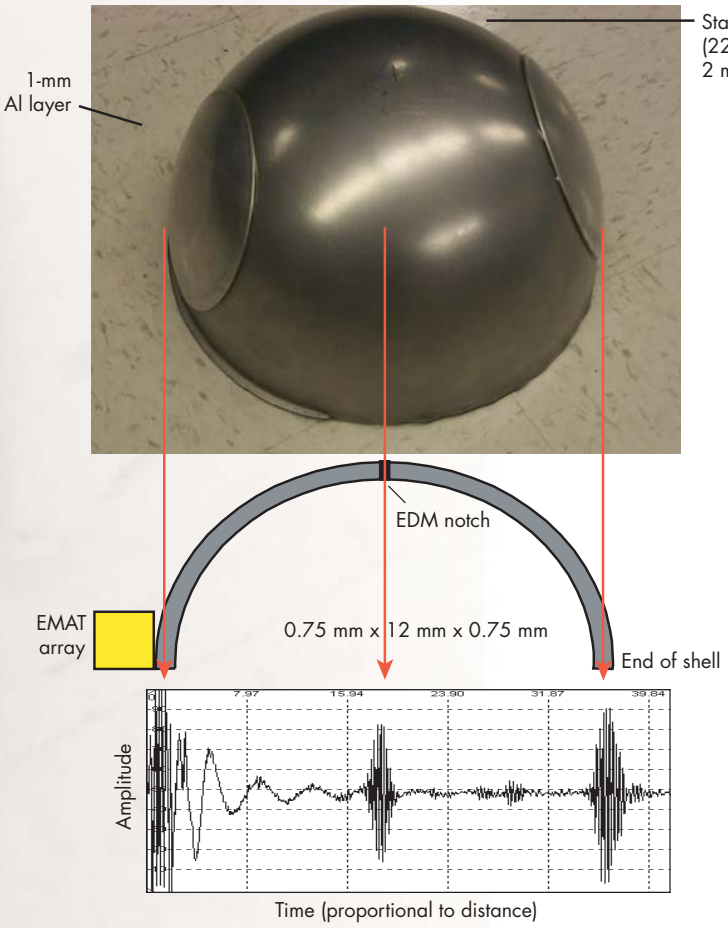

Figure 1. A sample RF waveform, showing the detection of an EDM notch using a guided wave on a curved stainless steel structure with A1 layers bonded at the sides with epoxy.

Project Goals

The goals of the guided wave technique were to detect a 20% through-wall notch in the bottom layer of a three-layer structure, and demonstrate the technique on curved structures. The project goal for the bulk wave technique was to detect a 1-mm drilled hole in the layer of interest.

Relevance to LLNL Mission

Both guided and bulk wave inspection techniques developed in this work will enhance LLNL's role in stockpile stewardship and inspecting weapons without disassembly. Experiments have also shown the scalability of guided waves to smaller curvatures, such as boiler tubing, and shows promise for application to NIF targets. In addition, the planar multilayer diffraction tomography reconstruction algorithms may image density distributions in explosives as well as shallow, near earth environments, to look for buried hazardous waste and covert trans-border tunnels.

FY2004 Accomplishments and Results

In FY2004, we evaluated the quantitative detection abilities of both techniques. Also, feasibility studies were conducted on programmatic-like structures. Experimental studies were conducted on tubes to analyze the scalability and range of applicable curvatures.

Multilayer plates of Al-epoxy-steel were constructed with notches of depths 10%, 20%, 30%, 50%, and 100% through-wall in the bottom layer. The guided wave technique showed sensitivity to detect the smallest (10%) flaw, exceeding our goal.

Electromagnetic acoustic transducer arrays were used to excite and detect an EDM notch at the pole of a curved multilayer structure, with excellent signal-to-noise (Fig. 1). Additional experiments were conducted on a stainless steel tube to show applicability to smaller curvatures. A through-wall crack and secondary cracking were created on a tube by bending it several times. A piezoelectric array excited a guided wave from one end of the tube and detected the cracks (Fig. 2).

For bulk waves, an Al-Cu planar sample was constructed with a side-drilled hole. Data were collected with a 5-MHz ultrasonic array. For the wave-based algorithm, the Green function was calculated to use diffraction tomography inversion algorithms that significantly simplify inversion. Both wave-based and bent-ray algorithms were used to reconstruct the data. Both images resulted in an accurate location and size of the hole. Holes of diameters 0.75 mm and 1.5 mm were later tested. The bent-ray algorithm imaged the 0.75-mm flaw, but the newer wave-based algorithm requires more work.

Related References

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3. Lehman, S. K., "Hilbert Space Inverse Wave Imaging in a Planar Multilayer Environment," *Journal of the Acoustical Society of America,* in press.
4. Fisher, K. A., "Development of a Quantitative Multiview Time Domain Imaging Algorithm Using a Fermat Correction," *Journal of the Acoustical Society of America,* in press.

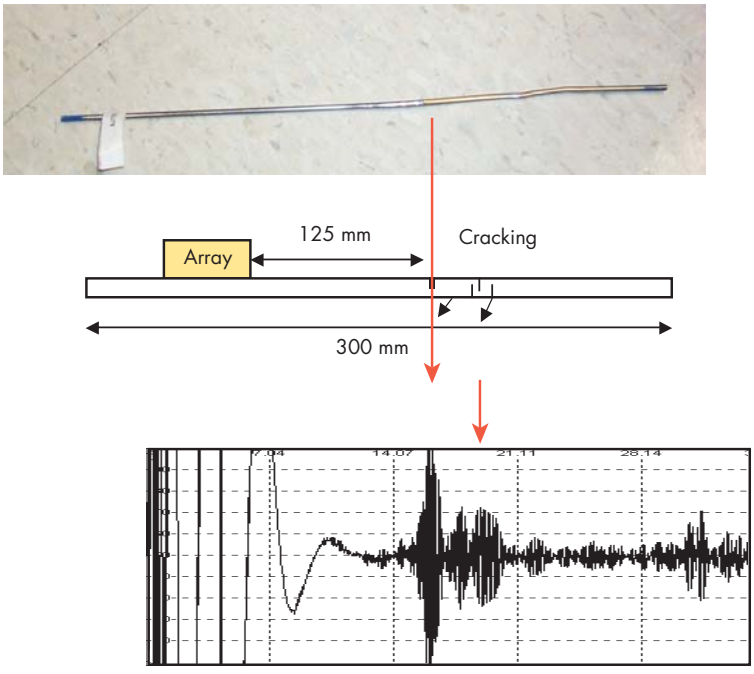

Figure 2. Sample results from an experiment on a stainless steel tube. Cracks in a 6-mm-diameter tube were detected by a guided wave with the array at 125 mm from the largest through-wall crack.

FY2005 Proposed Work

In our guided wave work, we will study incorporating time reversal techniques to improve resolution. Future bulk wave techniques will include shear waves and curvatures in the reconstruction algorithms to enhance signal-to-noise in images.